Direct Simulation of a Supersonic Turbulent Boundary Layer

S. Guarini, R. D. Moser, K. Shariff

Turbulence modeling introduces one of the major sources of uncertainty in the prediction of aeronautical flows. This statement is even truer for supersonic flows for which physical insight is lacking and for which any modeling ideas that do exist remain unvalidated because of lack of data.

Physical understanding and proper modeling of turbulent supersonic flow have seen a new beginning, however, thanks to a number of direct simulations by several groups in the last decade. For instance, an important effect which has recently come to light in free shear flows is a significant reduction with Mach number in the ability of the flow to produce turbulent shear stress from turbulent energy.

A direct simulation of a supersonic boundary layer at Mach 2.5 has just been completed. The turbulence is treated as being homogeneous (times a slow variation) along a transformed streamwise coordinate. The slow variation produces extra terms in the resulting equations. This technique not only obviates the need for an extended length in order for the turbulence to develop, but also allows the use of highly accurate Fourier expansions in the streamwise direction. A highly accurate B-spline representation is used in the wall-normal direction.

The supersonic boundary layer has been traditionally regarded, on the basis of experiment and analysis, as having weak compressibility effects, which can be accounted for by variations in mean fluid properties across the layer. One such analysis is due to Morkovin (1962); it proposes relationships between temperature and velocity fluctuation. The relationships are based on the hypothesis that fluctuations of stagnation temperature are much smaller than those of static temperature. However, the hypothesis itself is found to be invalid, a fact noted by Morkovin himself. Yet, a relationship for root-mean-square intensities which derives from the hypothesis was found to be valid. Its true basis remains to be uncovered.

Another relationship that follows from the hypothesis is that velocity and temperature fluctuation should be anti-correlated. The first part of the figure compares the correlation coefficient $R_{u'T'}$ of

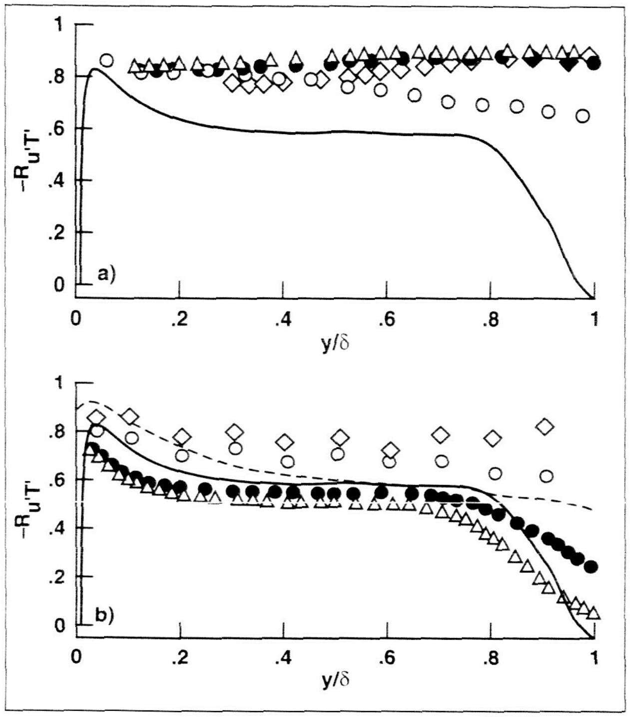

Fig. 1. Correlation coefficient $R_{u'T'}$ of velocity and temperature fluctuations: (a) comparison of simulation (solid) with various compressible experiments (symbols); (b) comparison with incompressible simulation (dashed) and incompressible experiments (symbols).

these two quantities in the simulation (solid line) with three experiments (symbols) at a similar Mach number. The disagreement is obvious: the experiments indicate a much better agreement with Morkovin's hypothesis than do the simulations. However, the second part of the figure shows that the simulation result (solid line) falls in the middle of several incompressible experiments. The reason for the discrepancy with compressible experiments remains to be explored. For example, is it the result of the low Reynolds number of the simulation compared with that of the experiment?

Point of Contact: K. Shariff
(650) 604-4729
shariff@nas.nasa.gov